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Spatial and temporal variations and controlling factors of potential evapotranspiration in China: 1956-2000

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Abstract: Based on the climatic data of 580 stations in China during 1956 and 2000, potential evapotranspiration are calculated by the Penman-Monteith Method recommended by FAO. The spatial and temporal distributions of the potential evapotranspiration over China and the temporal trends of the regional means for 10 major river basins and whole China are analyzed. Through a partial correlation analysis, the major climate factors which affect the temporal change of the potential evapotranspiration are analyzed. Major results are drawn as follows: 1) The seasonal and annual potential evapotranspiration for China as a whole and for most basins show decline tendencies during the past 45 years; for the Songhua River Basin there appears a slightly increasing trend. 2) Consequently, the annual potential evapotranspirations averaged over 1980-2000 are lower than those for the first water resources assessment (1956-1979) in most parts of China. Exceptions are found in some areas of Shandong Peninsula, western and middle basins of the rivers in Southwest China, Ningxia Hui Autonomous Region as well as the source regions of the Yangtze and Yellow rivers, which may have brought about disadvantages to the exploration and utilization of water resources. 3) Generally, sunshine duration, wind speed and relative humidity have greater impact on the potential evapotranspiration than temperature. Decline tendencies of sunshine duration and/or wind speed in the same period appear to be the major causes for the negative trend of the potential evapotranspiration in most areas.

Key words: potential evapotranspiration; Penman-Monteith formula; trend; controlling factors; China
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1 Introduction

Evaporation is one of the important components in the water and heat balances. The transpiration of vegetation and evaporation from soil are collectively called evapotranspiration. Potential evapotranspiration is not only the theoretical limitation of actual evapotranspiration but also the basis to evaluate it. Potential evapotranspiration has been widely used in researches related to dry and wet condition analysis of climate (Yang *et al*., 2002; Ma *et al*., 2003), utilization and assessment of water resources (Preliminarily Assessment to China Water Resources, 1981), crop water requirement and production control (Doorenbos and Pruitt, 1977), and eco-environment research such as desertification (Zhou *et al*, 2002). Currently, the second comprehensive assessment of water resources in China is being carried out. Potential evapotranspiration is one of the most important parts to be considered. It is influenced by a number of climate elements. In the past several decades, climate change has obviously occurred in China (e.g. Qian *et al*., 2004), which would have an effect on the potential evapotranspiration and further on the assessment of water resources. This study deals with the spatial and temporal patterns of the potential evapotranspiration over China in recent 45 years with a focus on the changes between the two water assessment periods (1956-1979 and 1980-2000).

In northern hemisphere, evaporation from the observations of pan evaporation generally decreases but the changes are not universal over the past 50 years (e.g. Peterson *et al*., 1995; Roderick and Farquhar,

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2002; Linacre, 2004). Yang *et al.* (2003), Qiu *et al.* (2003), Liu *et al.* (2004) and Ren *et al.* (2006) all found that water surface evaporation of pan show a decline tendency in northern China as well as in most parts of China. Some of these studies also attempt to explain the reason for the decreasing trend by using a number of relevant climate variables. However, no systematic examination has been done to deal with all possible controlling factors and their relative contributions to the trends.

Many methods can be used to estimate the potential evapotranspiration (e.g. Xu and Chen, 2005) and comparisons among various methods have been made (Jensen *et al.*, 1990; Li *et al.*, 2002; Liu *et al.*, 2003). There is a consensus that the Penman-Monteith method based on energy balance and mass transfer has a solid and physical basis. The method is thus capable in accurately reproducing the impacts of all relevant climatic elements and can be applied to different regions under varying climate conditions. In 1990, Penman-Monteith method was recommended as a standard to estimate reference crop evapotranspiration by FAO Specialist Panel. From then on, the method has been widely applied to many researches such as eco-environment, crop water requirement as well as drought monitor and assessment. This method has also been applied in China. However, due to the limited access to climate data and/or different focuses, the existing works mainly focus on parts of China (e.g. Guo *et al.*, 2001; Feng *et al.*, 2004; Xu *et al.*, 2006) or using a small number of selected stations over China (e.g. Thomas, 2000). These studies do not fully meet the demands of water resources assessment and plan-making for the whole country.

We focus on the spatial and temporal changes of the potential evapotranspiration estimated using Penman-Monteith method. The specific objectives of this study are: 1) to estimate monthly potential evapotranspiration with the Penman-Monteith method over China for 1956-2000; 2) to analyze the spatial and temporal patterns and changes of the potential evapotranspiration over 10 major drainage basins and the whole country; and 3) to identify the major climate factors which played a key role for the changes of the potential evapotranspiration in China.

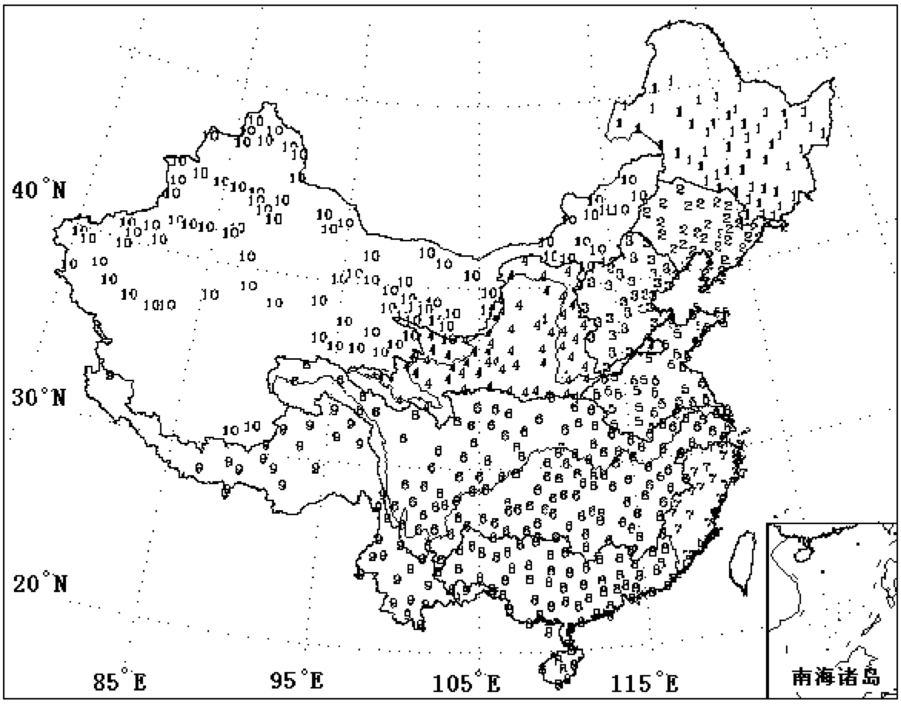

Figure 1 Distribution of 580 meteorological stations and 10 river basins in China
(The numbers denote the basins: 1. Songhua River; 2. Liao River; 3. Hai River; 4. Yellow River; 5. Huai River; 6. Yangtze River; 7. Southeast China; 8. Pearl River; 9. Southwest China; 10. Northwest China)

2 Data and methods

2.1 Data

Monthly mean sunshine duration (Su), mean maximum temperature (Tm), mean minimum temperature (Tn), mean relative humidity (Hu) and mean wind speed (Wn) at 580 stations over China are used to estimate potential evapotranspiration during 1956 and 2000. The distribution of meteorological stations and 10 river basins over China are plotted in Figure 1. Based on the monthly estimates, seasonal (Spring: March-May, Summer: June-August, Autumn: September-November, Winter: December-February) and annual potential evapotranspiration are further calculated.

2.2 Penman-Monteith method

Penman-Monteith formula is used to calculate the potential evapotranspiration of reference vegetation. The reference surface is assumed to be a flat surface that is completely covered by a grass with an assumed uniform height of 0.12 m and an albedo of 0.23 (Allen *et al*., 1998). The soil is assumed to be well watered. The reference evapotranspiration is taken as the potential evapotranspiration in this study. The formula is shown below:

$$ET_0 = \frac{0.408\,\Delta(R_n - G) + \dfrac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 U_2)} \tag{1}$$

where ET_0 is potential evapotranspiration (mm•d^{-1}), R_n is net radiation at reference surface (MJ•m^{-2}•d^{-1}), G is soil heat flux density (MJ•m^{-2}•d^{-1}), T represents monthly mean temperature (^{o}C), U_2 is the wind speed at 2 m height (m•s^{-1}), e_s is saturation vapour pressure (kPa), e_a is actual vapour pressure (kPa), Δ denotes the slope of vapour pressure curve versus temperature (kPa•℃$^{-1}$) and γ is psychrometric constant (kPa•^{o}C^{-1}). In calculating the radiation budget, solar radiation is usually evaluated by empirical formula:

$$R_s = (a_s + b_s S)R_a \tag{2}$$

where R_a is extraterrestrial radiation (MJ•m^{-2}•d^{-1}), S is percentage of sunshine, a_s and b_s are empirical constants. According to Zhu (1982), the empirical constants are determined for four regions in China, i.e. northeast region, eastern plain region, northwestern arid region and Tibetan Plateau region. The recommended constants a_s =0.25, b_s =0.5 by FAO are not chosen here. Calculation of R_n and G follows that of FAO. Monthly potential evapotranspiration is calculated by multiplying ET_0 with the number of days in that month.

2.3 Evaluating seasonal, annual and regional means

For seasonal and annual calculation over a region, it is assumed that the anomalies vary less than the absolute values among all the stations. Thus, if there is a missing value at a station, its anomaly is replaced with the mean of anomaly of the region and the regional mean is calculated as follows.

$$\overline{RX_i} = \overline{\Delta RX_i} + \overline{RX_{1971-2000}} \qquad i = 1956, 2000 \tag{3}$$

where $\overline{RX_i}$ is the regional mean of each year, i is annual index, $\overline{\Delta RX_i}$ is the regional mean anomaly with respect to the reference period 1971-2000 which is taken by averaging the anomalies of all the available stations in the region, and $\overline{RX_{1971-2000}}$ is the regional mean averaged from 1971 to 2000.

2.4 Partial correlation

Five climate factors are used to calculate potential evapotranspiration. What are the relative importance of these factors in determining the potential evapotranspiration change? The answer to this question may be sought by a linear regression analysis as the strength of the correlation can be used to measure the extent to which the potential evapotranspiration is determined by a factor. However, a univariate analysis is most likely not being appropriate as the five factors may be strongly linked to each other. Partial correlation method may be useful in dealing with this problem as it seeks the 'real' correlation between potential evapotranspiration and a factor by eliminating the influences of all other factors. It is assumed that the larger the partial correlation is, the more important the factor is for the changes of potential evapotranspiration.

3 Results and discussion

3.1 Characteristics of spatial distribution

3.1.1 Distributions of annual and seasonal potential evapotranspiration The low centers of the annual potential evapotranspirations are mainly located in the northern and eastern parts of Northeast China (Figure 2), and some parts of the upper reaches of the Yellow and Yangtze rivers because of the low air temperature. As a result of poor sunshine condition, humid climate and weak wind speed, another sub-low center lies in the middle reaches of the Yangtze River. The high centers of annual evapotranspiration are located in most desert areas in the river basins of Northwest China as a result of good radiation condition, strong wind and dry climate. The sub-high centers lie in Yunnan province and Hainan island because of high temperature and good sunshine condition. In spring, the pattern is similar to that of annual evapotranspiration. In summer, the seasonal values appear increase in most parts of

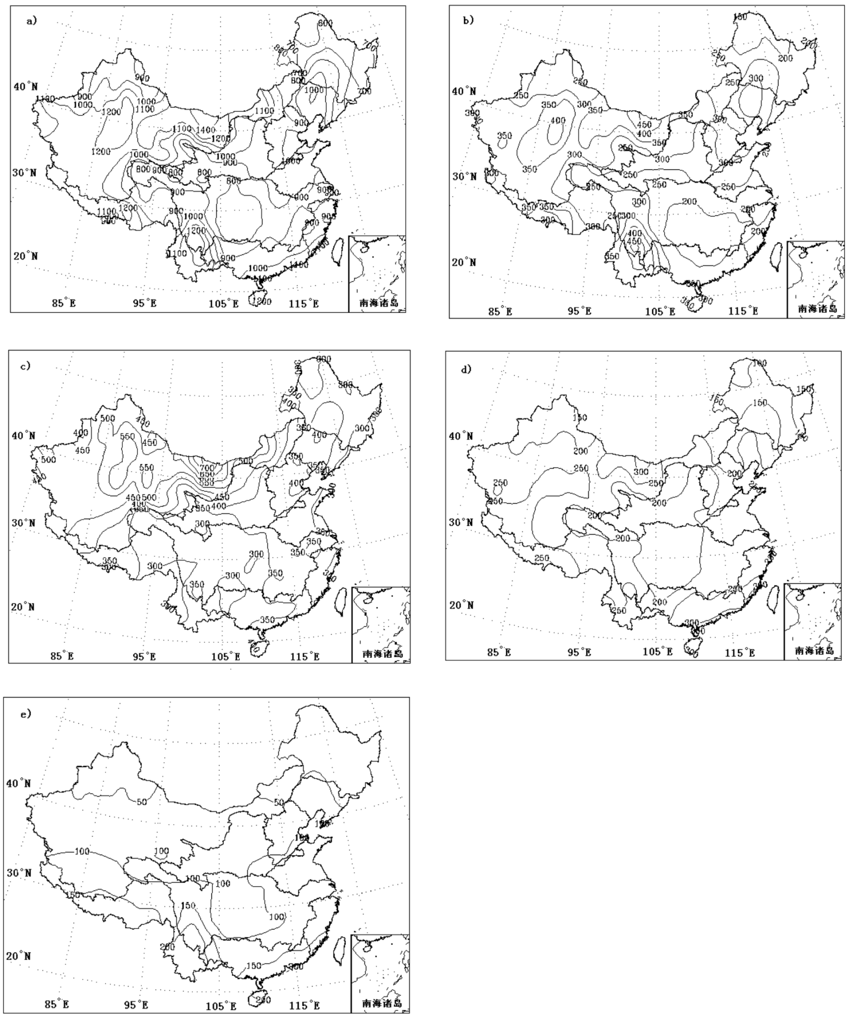

Figure 2 The patterns of seasonal and annual potential evapotranspiration averaged from 1956 to 2000 over China estimated by Penman-Monteith method (unit: mm)
(a. annual; b. spring; c. summer; d. autumn; e. winter)

Table 1 The normal seasonal and annual potential evaportranspiration of 10 river basins and China (based on the average of 1956-2000) (unit: mm)

Name of basins	Annual	Spring	Summer	Autumn	Winter
Songhua River	733.6	227.3	329.7	147.4	29.2
Liao River	879.4	276.2	346.8	191.2	65.5
Hai River	964.7	300.0	377.3	201.2	86.3
Yellow River	929.1	276.4	377.3	188.0	87.3
Huai River	960.4	265.5	362.2	224.2	108.3
Yangtze River	881.9	228.8	338.8	202.1	112.2
Rivers in Southeast China	929.5	200.9	352.4	246.4	129.7
Pearl River	1020.0	246.3	344.7	266.7	162.5
Rivers in Southwest China	1059.6	322.5	328.6	239.4	168.7
Rivers in Northwest China	1069.6	314.0	475.7	215.2	64.6
China	941.5	263.2	368.7	210.1	99.4

China compared to those in spring, except a decrease in some parts of Southwest China with higher humidity. Zonal pattern is clear in winter.

3.1.2 Regional mean potential evapotranspiration of 10 river basins Normal annual potential evapotranspiration averaged over China is 941.5 mm (averaged period is from 1956 to 2000) with 28% in spring, 39% in summer, 22% in autumn and 11% in winter. In the river basins of Northwest China, the

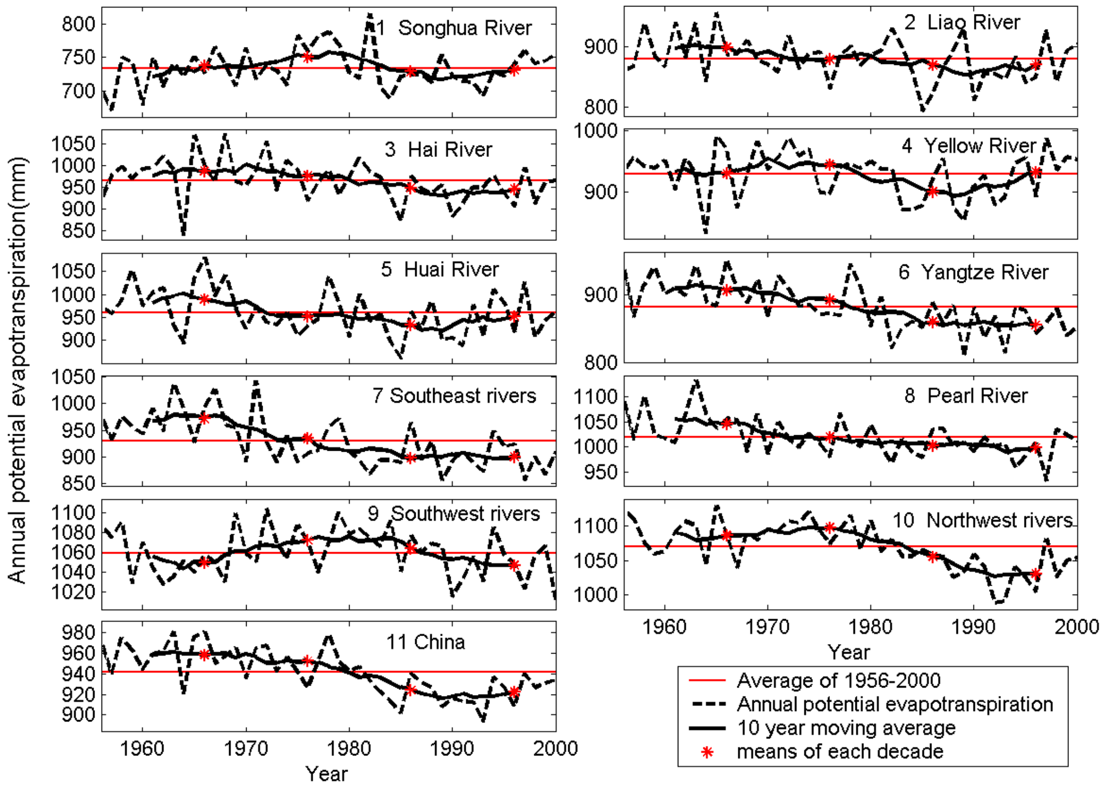

Figure 3 The time series of annual potential evapotranspiration of 10 river basins and China during 1956 to 2000. The thick line is the 10 year moving mean, star (*) denotes the mean of each decade, and the thin line represents the normal during this period. The dash line denotes the annual potential vapotranspiration.

annual value is the largest as a result of the abundant sunshine and dry climate (Table 1). In the Songhua River Basin, the normal annual mean temperature is the lowest of China that produced the lowest annual evapotranspiration. For the Yangtze River, the minimum annual sunshine hours, relatively low wind speed as well as rather humid climate lead to the minimum annual evapotranspiration in south of China. Because of generally more sunshine hours, drier air and stronger wind speed in spring, the seasonal potential evapotranspirations are greater than those in autumn, except for the river basins in Southeast China and the Pearl River delta. These basins are located in the south of China and are affected by the monsoon rainfall earlier than the other places. In winter, the seasonal potential evapotranspiration decreases from south to north gradually.

3.2 Variation and trends of annual and seasonal potential evapotranspirations

3.2.1 Decadal variation The 10-year mean annual potential evapotranspiration of China and most basins are more than normal during the 1960s to the 1970s and less than normal since the 1980s (Figure 3). In basins of the Songhua River, the Yellow River, the Huai River as well as the rivers in Southeast China, the 10-year mean annual potential evapotranspirations arrived at the bottom during the 1980s and were on the rise though still less than normal (with one exception in the Yellow River Basin) during the 1990s.

3.2.2 Trends of annual and seasonal potential evapotranspirations The annual potential evapotranspirations of the country and most basins have decreasing trends except for the Songhua River Basin where a slight increasing trend appeared (Table 2). Annual potential evapotranspiration of the whole country decreases at a rate of -1.18 mm/yr which is statistically significant at the 0.01 level. The relative change to regional mean is about -5.7% during the past 45 years. This agrees with the results of Ren and Guo (2005) who study the trend of Pan evaporation in China during the same period of time. In addition, the annual trends estimated here are broadly consistent with those given by Chen *et al*. (2005) who estimates only the annual trend with the same method over the period 1951-2000. The significant decreasing trends of spring, summer and autumn are responsible for the decreasing annual trends.

Table 2 Trends of annual and seasonal potential evapotranspiration of the 10 river basins and whole country during 1956 to 2000

(T denotes the trend (mm/yr), RT is change during the 45 years relative to the regional mean (%))

Name of basins		Songhua River	Liao River	Hai River	Yellow River	Huai River	Yangtze River	Rivers in Southeast China	Pearl River	Rivers in Southwest China	Rivers in Northwest China	China
Annual	T	0.21	-0.73	-1.2#	-0.43	-1.3#	-1.73*	-2.2*	-1.57*	-0.28	-1.67*	-1.18*
	RT	1.3	-3.7	-5.6	-2.1	-6.1	-8.8	-10.6	-6.9	-1.2	-7.0	-5.7
Spring	T	0.05	-0.43*	-0.45	-0.1	-0.01	-0.16	-0.15	-0.6*	-0.01	-0.47*	-0.25#
	RT	1.0	-7.0	-6.8	-1.6	-0.1	-3.1	-3.4	-10.9	-0.1	-6.7	-4.2
Summer	T	0.04	-0.26	-0.54	-0.34	-1.08*	-1.15*	-1.31*	-0.46#	-0.07	-0.77*	-0.65*
	RT	0.5	-3.4	-6.4	-4.0	-13.4	-15.3	-16.7	-6.1	-0.9	-7.3	-7.9
Autumn	T	0.06	-0.09	-0.14	0.02	-0.15	-0.3*	-0.51*	-0.3	-0.1	-0.39*	-0.21*
	RT	1.9	-2.1	-3.0	0.5	-2.9	-6.6	-9.3	-5.1	-1.9	-8.1	-4.4
Winter	T	0.06	0.04	-0.07	-0.01	-0.03	-0.12	-0.2	-0.23	-0.06	-0.02	-0.07
	RT	9.8	2.9	-3.5	-0.6	-1.3	-4.9	-7.1	-6.4	-1.6	-1.0	-3.2

(Note: * statistically significant at the 0.01 level, # statistically significant at the 0.05 level.)

In southern China, the values of the basins of the Huai River, the Yangtze River, the rivers in Southeast China and the Pearl River show significant decreasing trends on annual scale and in summer during the past 45 years. But in the basin of the rivers in Southwest China, no clear trends are found for the four seasonal and annual values. The changes of the basins in northern China are more complicated. In the Songhua River Basin, all seasonal and annual values have slightly increasing trends. In the other basins, on the other hand, the annual and seasonal values have slightly decreasing trends. But in the river basins of Northwest China, all seasons except winter show a significant decreasing trend.

3.3 Spatial pattern of the changes in potential evapotranspiration between 1980-2000 and 1956-1979

The spatial patterns of annual and seasonal potential evapotranspiration between 1980-2000 and 1956-1979 are compared. The choice of the year 1980 as a breaking point is due to the facts that the study period of the first water resources assessment of China is from 1956 to 1979 and the temperature in China has changed significantly since the 1980s with a warming trend (e.g. Wei *et al*., 2003). How does the potential evapotranspiration response to the climate change?

In most areas of China, the mean annual values of later period have showed decreasing trends (Figure 4). But in some areas of Shandong Peninsula, western and middle basins of rivers in Southwest China, Ningxia Hui Autonomous Region as well as the source regions of the Yangtze and Yellow rivers, the values have a slightly increasing trend during recent 20 years. Li *et al*. (2000) also found that the evapotranspiration has been increased in the upper reaches of the Yellow River since the 1980s using the Penman formula.

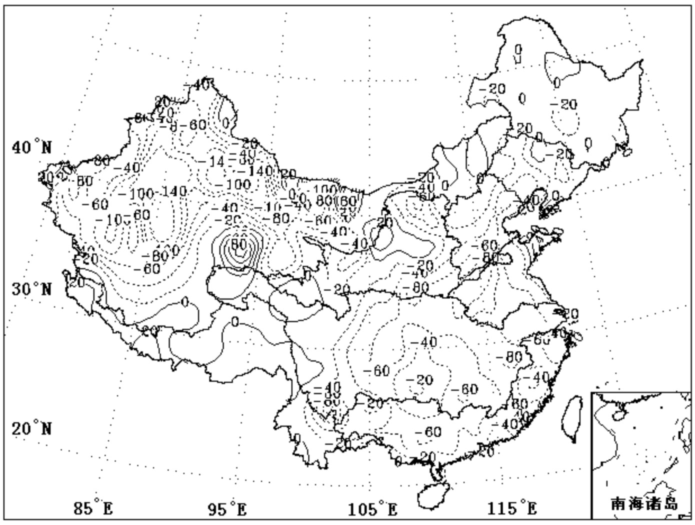

Figure 4 Difference of mean annual potential evapotransporation between periods of 1980-2000 and 1956-1979 (unit: mm)

National and regional means of annul potential evapotranspiration of the 10 river basins generally decrease during 1980 and 2000 (Table 3), but the differences vary with basin and season.

In the basins of the Hai River, the Huai River, the Yangtze River, the rivers in Southeast China, the Pearl River, the rivers in Northwest China and the whole country, the decreasing trends of annual potential evapotranspiration are statistically significant, which means about 31.5 mm to 56.4 mm less than those in the previous period. For these basins and the whole country, the large part of decrement in annual potential evapotranspiration mainly occurs in summer except the Hai River and Pearl River basins in spring.

In the other basins, the decreasing trends of the annual and seasonal potential evapotranspirations are generally not significant except those in the Liao River Basin in spring and Yellow River Basin in summer. Small increasing trends are found in the Songhua River Basin in winter and the Yellow River in autumn.

Table 3 The absolute and relative differences of annual and seasonal potential evapotranspirations between 1980-2000 and 1956-1979 of the 10 river basins and whole China

(D: the absolute difference (mm); RD: the relative difference to mean of the early period (%))

Name of basins		Songhua River	Liao River	Hai River	Yellow River	Huai River	Yangtze River	Rivers in Southeast China	Pearl River	Rivers in Southwest China	Rivers in Northwest China	China
Annual	D	-7.4	-17.6	-31.5#	-19.9	-36.2#	-46.9*	-56.4*	-34.2*	-5.3	-44.2*	-32.6*
	RD	-1.0	-2.0	-3.2	-2.1	-3.7	-5.2	-5.9	-3.3	-0.5	-4.0	-3.4
Spring	D	-1.2	-10.0#	-13	-5.5	-0.9	-4.6	-5.9	-15.3*	-1.1	-13.5*	-7.5*
	RD	-0.5	-3.6	-4.2	-2.0	-0.3	-2.0	-2.9	-6.0	-0.4	-4.2	-2.8
Summer	D	-6.2	-5.7	-12.3	-13.8#	-29.3*	-29.1*	-28.1*	-6.2	-0.3	-19.7*	-16.8*
	RD	-1.9	-1.6	-3.2	-3.6	-7.8	-8.3	-7.7	-1.8	-0.1	-4.1	-4.5
Autumn	D	-1.4	-1.7	-3.7	0.2	-4.1	-9.5*	-16.7*	-7.2	-0.9	-9.7*	-6.0*
	RD	-1.0	-0.9	-1.8	0.1	-1.8	-4.6	-6.6	-2.7	-0.4	-4.4	-2.8
Winter	D	1.6	-0.4	-2.9	-0.7	-1.9	-3.6#	-5.2	-5.9	-2.4	-0.9	-2.3
	RD	5.6	-0.6	-3.3	-0.8	-1.7	-3.2	-3.9	-3.6	-1.4	-1.4	-2.3

(The meaning of symbols are the same as in Table 2, but for t-test)

3.4 Controlling factors for potential evapotranspiration

Table 4 lists the relationships between climate factors and potential evapotranspirations of the 10 river basins and the whole country on annual and seasonal scales. From Table 4, it is seen that sunshine duration, mean wind speed, mean maximum temperature and minimum temperature have positive relationship with potential evapotranspiration, while relative humidity is negatively correlated to potential evapotranspiration. In most river basins and the whole country, sunshine duration, mean wind speed and relative humidity are major controlling factors for most seasonal and annul potential evapotranspirations, whereas mean maximum temperature and minimum temperature play a relatively minor role.

Table 4 Relationships between climate factors and annual/seasonal potential evapotranspiration of 10 river basins and the whole country

Name of basins	Annual	Spring	Summer	Autumn	Winter
Songhua River	***-Hu***, ***Su***, **Tm**	*-Hu*, ***Wn***, ***Su***, **Tm**	*-Hu*, *Su*, ***Wn***, Tm	***-Hu***, Tm, ***Wn***	*-Hu*, ***Wn***, **Tm**, **Tn**
Liao River	*-Hu*, ***Su***, **Tm**, ***Wn***	***Wn***, -Hu, **Tm**, ***Su***	***Su***, *-Hu*, ***Wn***, Tm	*-Hu*, ***Wn***, Tm	*-Hu*, ***Wn***, **Tm**
Hai River	***Wn***, *-Hu*, ***Su***, **Tm**	*-Hu*, ***Wn***, Tm, ***Su***	***Su***, *-Hu*, ***Wn***, Tm	*-Hu*, ***Wn***	*-Hu*, ***Wn***, **Tm**
Yellow River	***Wn***, ***Su***, *-Hu*	*-Hu*, ***Wn***, *Su*, Tm, **Tn**	***Su***, -Hu, ***Wn***, **Tn**	***Wn***, *-Hu*, **Tm**, *Su*	*-Hu*, ***Wn***, **Tm**, ***Su***
Huai River	***Su***, *-Hu*, ***Wn***	*-Hu*, *Su*, ***Wn***, Tm	***Su***, -Hu, ***Wn***, *Tm*	*-Hu*, ***Wn***, Tm	*-Hu*, ***Wn***, Tm, ***Su***
Yangtze River	***Su***, **Tn**, *-Hu*, ***Wn***	*-Hu*, ***Su***, ***Wn***	***Su***, **-Hu**	***Wn***, *-Hu*, ***Su***	-Hu, ***Wn***
Rivers in Southeast China	***Su***, *-Hu*, ***Wn***, **Tn**	***Su***, ***-Hu***, Tn	***Su***, -Hu, *Wn*, *Tm*	*-Hu*, ***Wn***, ***Su***	-Hu, ***Wn***, *Su*, **Tn**
Pearl River	***Su***, *-Hu*, ***Wn***, **Tn**	**Su**, ***Wn***, -Hu, Tn	***Su***, *-Hu*, ***Wn***, **Tn**	***Su***, *-Hu*, ***Wn***, **Tn**	-Hu, ***Wn***, ***Su***
Rivers in Southwest China	*Su*, *Wn*, **-Hu**, *Tm*	*Su*, *Wn*, **-Hu**, Tm, **Tn**	*Su*, *-Hu*, *Wn*, **Tn**	*Su*, ***Wn***	***Wn***, Su, Tm, **-Hu**
Rivers in Northwest China	***Wn***, *-Hu*, **Tm**, *Su*	***Wn***, Tm, -Hu, Su	***Wn***, **-Hu**, **Tm**, ***Su***	***Wn***, -Hu, Tm	***Wn***, *-Hu*, **Tn**, **Tm**
Whole country	***Su***, ***Wn***, *-Hu*, **Tm**	*-Hu*, ***Wn***, ***Su***, Tm	*Su*, ***Wn***, -Hu, Tm	***Su***, *-Hu*, ***Wn***	*-Hu*, ***Wn***, ***Su***, **Tn**

The table lists the factors with significant (⩽0.05 level) partial correlation coefficients in descending order. The minus (-) denotes that negative partial correlation lies between potential evapotranspiration and climate factors. Italic type character represents the climate factor decline during the past 45 years. Thick type character represents the trend with statistical significant at ⩽ 0.05 level.

For annual potential evapotranspiration, the major controlling factors change with latitude from relative humidity in the Songhua and the Liao river basins to wind speed in the basins of the Hai River, the Yellow River and the rivers in Northwest China and further to sunshine duration in the other basins of southern China. For the whole country, sunshine duration is the most important controlling factor. Similar latitudinal changes of major controlling factors for potential evapotranspiration are also found in spring. In most basins of northern China, relative humidity or mean wind speed have close relationship with potential evapotranspiration. In southern basins of China, the situation change and the sunshine duration are more important. In summer, sunshine duration and humidity are major controlling factors affected by summer monsoon except for the basin of the rivers in Northwest China. In autumn and winter, relative humidity or wind take the control position in most basins. Only in some southern basins, such as the Pearl River and the rivers in Southwest China, the sunshine duration still plays a dominant role.

In order to identify the relative contributions of all the factors to the change of potential evapotranspiration, we further analyze the change of each factor during the past 45 years. From Table 4, it is seen that seasonal and annul sunshine duration and mean wind speed of most basins and the whole country show significant declining trends during 1956 and 2000. The declining trends of annual sunshine duration and wind speed are consistent with previous studies by Li *et al*. (1998) and Wang *et al*. (2004) respectively. Li *et al*. (1998) found that the global radiation and direct radiation in most parts of China had significant decreasing trends during 1960 and 1990 as a result of the increased atmospheric turbidity and aerosol. Wang *et al*. (2004) attributed the significant decline of wind speed in China during the past 50 years to the weakening winter and summer monsoon. Besides the change of atmospheric circulation, change of land surface such as urbanization may also have an impact on the decrease of wind. Significant decreasing trends in sunshine duration (or solar irradiation) and wind speed may have resulted in the declining tendencies of the potential evapotranspiration in most basins and the whole country. Relative humidity of different basins and seasons do not show a consistent and significant trend. These lead to the conclusion that the change of relative humidity is probably not the dominating factor for the trend of potential evapotranspiration during the past 45 years. But in the Songhua River Basin, the relative humidity is the principal controlling factor for all seasons. As a result of the decreasing relative humidity and increasing maximum/minimum temperature, the potential evapotranspiration there shows a slightly increasing trend. These results are similar to the studies by Ren *et al*. (2006) and Guo *et al*. (2005). They try to use the method of correlation analysis between pan observation and climate factors to explain the change of water evaporation.

As a whole, the variations of annual and seasonal potential evapotranspirations of each basin reflect the comprehensive function of each climate factor. Among these factors, the changes of principal factors play a key role in the change of potential evapotranspiration. The other factors would enhance or offset the impact of the major factors according to their change and relation with potential evapotranspiration.

4 Conclusions

From the above analysis, some conclusions are drawn as follows:

(1) At a basin scale, annual potential evapotranspiration is the highest in the river basins of Northwest China and the smallest in the Songhua River Basin.

(2) For China as a whole and most basins the 10-year means of potential evapotranspiration are more than normal during the 1960s and 1970s and less than normal since the 1980s. For the basins of the Yellow River, the Huai River, the Songhua River and the rivers in Southeast China, the potential evapotranspirations are on the rise during the 1990s but the values are still less than the normal except for the Yellow River Basin.

(3) For China as a whole and the river basins in Northwest China, both the annual and seasonal potential evapotranspirations have a significant decreasing trend except in winter during the past 45 years. The seasonal and annual potential evapotranspirations for most of the other basins show the declining trends except for the Songhua River Basin with a slightly increasing trend. Particularly in the basins of southern China (except for the river basins in Southwest China) the declining trends are significant on annual scale and in summer.

(4) Compared with averages of 1956-1979, not only annual but also seasonal potential evapotranspirations averaged over 1980-2000 show a decreasing trend in most parts of China. But in some places of Shandong Peninsula, western and middle basins of rivers in Southwest China, Ningxia Hui Autonomous Region as well as the source regions of the Yangtze and Yellow rivers there is a nincreasing trend.

(5) Sunshine duration or solar radiation and wind speed are the major climate factors which affect the change of potential evapotranspiration in China during the past 45 years.

(6) Since the 1980s, the annual mean temperature has been increasing, particularly during the end of the 1990s. However, the potential evapotranspiration calculated by Penman-Monteith method during the same period does not show an increasing trend. This demonstrates that potential evapotranspiration does not only depend on air temperature. The factors such as solar radiation, wind speed and relative humidity seem to be more important in determining the changes in potential evapotranspiration than the air temperature for China.

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